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RECLAMATION OF WHITE-ALKALI SOILS IN THE IMPERIAL VALLEY

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EDWARD E. THOMAS[3]

INTRODUCTION

ALTHOUGH A LARGE PART of the soil of the Imperial Valley, California, is highly productive, several thousand acres within it contain toxic amounts of soluble salts. In certain areas these salts were present in the surface soil before irrigation water was brought into the Valley; however, much of the land, which at the outset was free from an accumulation of soluble salts in the surface horizons, now shows excessive amounts. Large amounts of irrigation water have been used, and the water actually applied as irrigation, together with seepage from earthen canals, has saturated the subsoil and has brought the level of the ground water almost to the surface in many places over the Valley. Certain horizons of the subsoil originally contained appreciable amounts of soluble salts, and wherever the ground water has risen, more or less of these soluble salts have been brought to the surface by capillarity.

The irrigation water itself also contains a low concentration of dissolved salts which have tended to accumulate in the soil where the drainage conditions were poor. In such areas the soluble salts of both the subsoil and the irrigation water thus have become concentrated near the surface and have made the soil toxic to plants. This has occurred in many places in the Valley.

SOILS

Much of the soil of the Imperial Valley was formed by the deposition of material brought down by the Colorado River. Sedimentary soils of this nature are composed of various layers, such as sand, fine sand, loam, clay loam, silty clay, and clay. The location of these layers in the soil profile determines the type of most of the soils in the southern end of the Imperial Valley.

Reports of soil surveys which have been made in the Imperial Valley at four different times have been published.[4] The first two surveys were

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[1] Received for publication April 2, 1936.

[2] Paper No. 338, University of California Citrus Experiment Station and Graduate School of Tropical Agriculture, Riverside, California.

[3] Associate Chemist in the Experiment Station.

[4] Holmes, J. Garnett, *et al.* Soil survey of the Imperial area, California. U. S. Dept. Agr. Bur. Soils Field Operations 1903, Rept. 5:1219–48. 1904.

Kocher, A. E., *et al.* Soil survey of the Brawley area, California. U. S. Dept. Agr. Bur. Soils Field Operations 1920, Rept. 22:641–716. 1925.

Means, T. H., and J. Garnett Holmes. Soil survey around Imperial, California. U. S. Dept. Agr. Bur. Soils Field Operations 1901, Rept. 3:587–606. 1902.

Strahorn, A. T., *et al.* Soil survey of the El Centro area, California. U. S. Dept. Agr. Bur. Soils Field Operations 1918, Rept. 20:1633–87. 1924.

made in 1901 and 1903 by the United States Department of Agriculture Bureau of Soils and the last two in 1918 and 1919–20, by the United States Department of Agriculture Bureau of Soils in coöperation with the University of California.

The four principal soil series[5] of the Valley are the Imperial, Meloland, Holtville, and Rositas. The Imperial series consists of a fine-textured surface soil underlain with a slowly pervious subsoil of similar character. In the Meloland series the surface soil is pervious and relatively coarse-textured but is underlain with a heavy subsoil very similar in character to that of the Imperial series. The Holtville series consists of a fine-textured surface soil underlain with a pervious, coarse-textured or sandy subsoil. The surface soils of this series are very similar to those of the Imperial series. The Rositas series consists of a loose, coarse-textured, pervious surface soil and subsoil. In general, the soils of the Valley usually contain considerable lime and little organic matter.

The predominant soluble salts in the Imperial Valley soils are the two neutral salts, sodium chloride (common salt) and sodium sulfate (Glauber's salt). In many places calcium sulfate, calcium chloride, magnesium chloride, and magnesium sulfate are also found in large amounts. The excessive accumulations of soluble salts on or near the surface of the soil are usually found overlying fine-textured and relatively dense subsoils.

IRRIGATION AND DRAINAGE

The Colorado River water contains an appreciable amount of dissolved salts. The mean of 41 analyses[6] of samples taken at Yuma, Arizona, showed the composition of the water in milliequivalents per liter to be: bicarbonate (HCO_3), 2.99; chloride (Cl), 3.20; sulfate (SO_4), 7.94; calcium (Ca), 4.90; magnesium (Mg), 2.86; and sodium (Na), 6.44. Some of these, namely the sodium compounds or alkali salts, are detrimental in most cases, while the calcium compounds are usually beneficial from an irrigation standpoint.

Irrigation was first introduced into the Imperial Valley in June, 1901, and within two years several thousand acres were under cultivation. But not until large areas had been injured by a rising water table, with the consequent accumulation of alkali, was there any systematic effort made to control the problem through drainage. By 1929 a very extensive system of drain ditches had been installed. Many of the farmers have subsequently added to the system by installing lateral ditches on their own property in order to facilitate the drainage.

[5] Cosby, S. W., and L. G. Goar. Soils and crops of the Imperial Valley. California Agr. Exp. Sta. Cir. 334:1–108. 1934.

[6] Scofield, C. S., and L. V. Wilcox. Boron in irrigation waters. U. S. Dept. Agr. Tech. Bul. 264:58. 1931.

In certain areas the water table has been materially lowered by the drain ditches, while in other sections the drains have produced but little effect. This variation in the effectiveness of the drains is caused by peculiarities in the subsoil. Where the ditches cut into a porous subsoil layer, the drains have been effective in lowering the water table. But certain areas are underlain with a clay heavy enough to restrict the movement

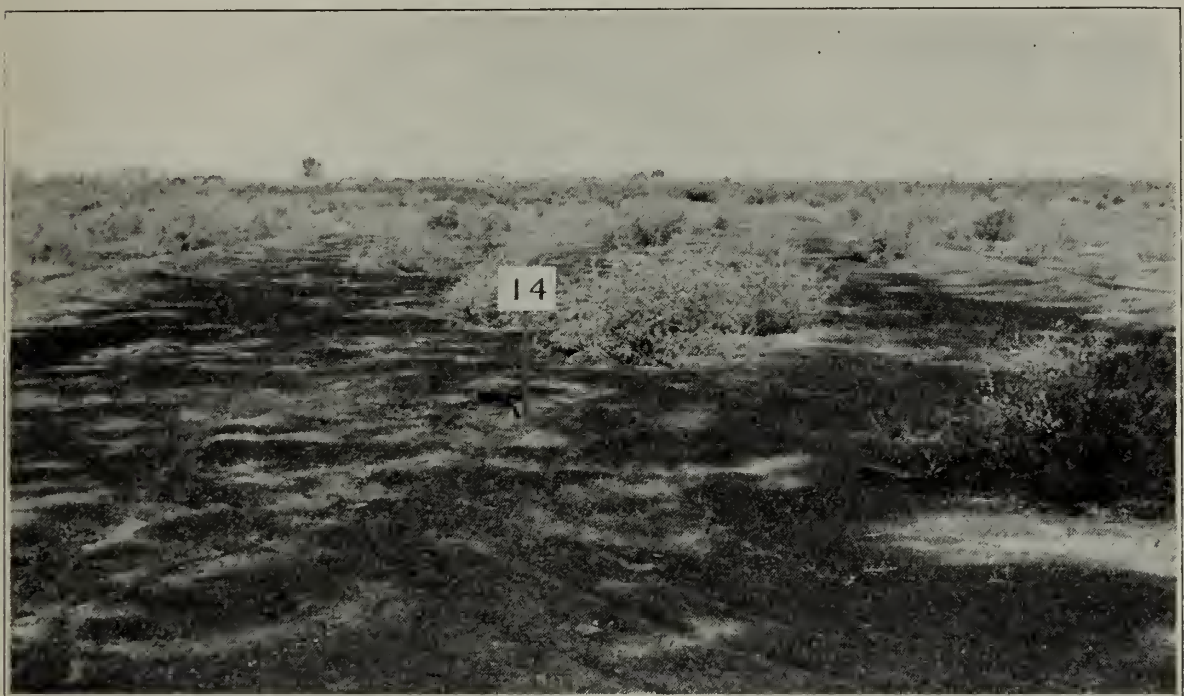

Fig. 1.—General condition of soil before reclamation experiments were begun. The calcium chloride in the soil had absorbed enough moisture to make the surface moist, as shown in the immediate foreground. Photographed January 17, 1929. (From Hilgardia, Vol. 8, No. 5.)

of water; in such places standing water is often found near the surface of the soil, even where a large drain ditch is located within a short distance.

Much of this poorly drained soil belongs to the Meloland series. As stated already, this soil series is characterized by sandy or sandy loam surface soil underlain with slowly pervious clay layers. The irrigation water has penetrated the sandy surface layers and has accumulated above the dense sublayers. In the course of time a high water table has resulted. Also, the seepage from the irrigation canals and ditches has tended to accumulate above the slowly pervious subsoil layers. The consequent high water table has brought the soluble salts to the surface where they have accumulated.

In still other instances there are silty clay and clay surface soils underlain with sandy layers (Holtville series) that are saturated with water containing a large amount of soluble salts. Such soils have been rendered unproductive by the rise of soluble salts from the sandy saturated layer. In many cases the water in the sandy layer is often under pressure which

tends to force it up through the surface layers and hastens the movement of water toward the soil surface.

A survey of the alkali conditions in the Imperial Valley shows that the soils contain very little black alkali (sodium carbonate); in many places, however, very high concentrations of white alkali occur. Where the subsoil is fine-textured, the movement of water is restricted, a fact which greatly increases the difficulty of reclamation, especially from a leaching standpoint.

TABLE 1

TREATMENTS APPLIED TO RECLAMATION PLOTS

Plot No.	Treatment	Amount, pounds per acre
10	Gypsum	3,000
11	Untreated	0
12	Manure	20,000
13	Sulfur	500
14	Untreated	0
15	Sulfur	500
	Gypsum	3,000
16	Manure	20,000
	Gypsum	3,000
17	Untreated	0
18	Manure	20,000
	Sulfur	500

RECLAMATION EXPERIMENT

An alkali reclamation experiment has been carried out on a typical area near El Centro where alkali has accumulated in consequence of poor drainage. The surface soil of the experimental tract is a silty clay with a subsoil of similar character down to a depth of 8½ to 9½ feet. This is underlain with a sandy layer 3 feet or more in thickness. This area was good farm land until a rising water table brought the soluble salts to the surface, where the concentration became so high as to cause serious injury to the crops (fig. 1). The water table had risen to within 18 inches of the surface, where it remained until a drain ditch was dug 2,000 feet away. The ditch penetrated a sandy layer, in consequence of which the water table was lowered to the depth of from 4 to 5 feet from the surface of the soil. In order to facilitate the drainage, a lateral ditch was dug within 200 feet of the experimental tract.

The area selected for experiment was divided into ½-acre plots. Each plot was carefully leveled so that irrigation water could be distributed uniformly over the entire surface of the soil. This step is very important in alkali reclamation because of the necessity of leaching the soluble salts out of the soil by flooding with water.

Six of the experimental plots were treated with gypsum, manure, or sulfur, or combinations of these materials (table 1). Three of the plots were left untreated as checks. In May, 1929, the treatments were applied to the soil and plowed under, after which the soil was cultivated until a good seed bed was secured.

Sesbania, a plant relatively tolerant of alkali, was sown on May 22 and allowed to grow during the summer months. During this period the

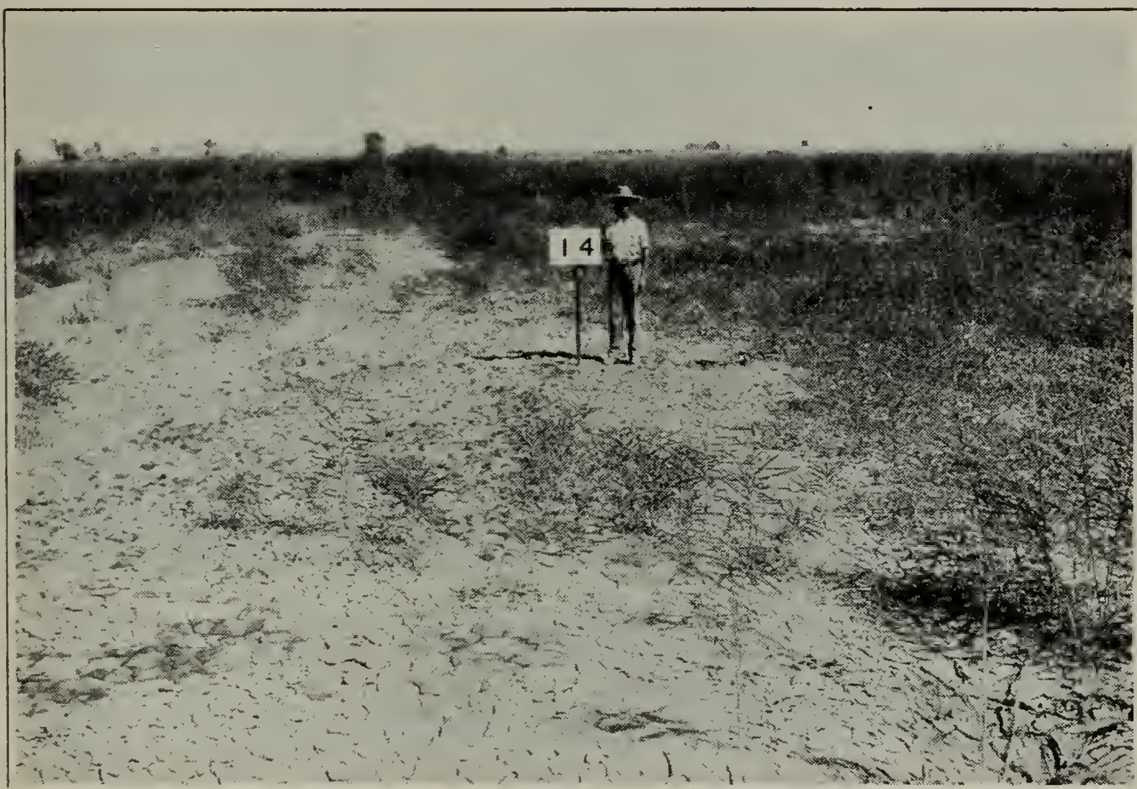

Fig. 2.—This photograph (September 11, 1929), taken from the same place as that of figure 1, shows the growth of sesbania before the soil was leached.

soil was irrigated sufficiently to supply adequate moisture for the sesbania but was not leached (fig. 2). Ninety days from the date of seeding, the crop was plowed under as a green manure, or covercrop; the land was releveled as soon as the sesbania plants had sufficiently decomposed. The plots were then flooded for 11 days, after which time the water standing on the surface was drained away and the soil was allowed to dry for plowing.

The silt in the irrigation water of the Imperial Valley tends to clog the pores of the soil and thus to hinder penetration and leaching. By plowing from time to time, however, the silt and the soil become mixed and will again take water readily.

After the plowing, the plots were flooded a second time to a depth of from 4 to 6 inches for a period of 6 weeks. At the end of this time a second plowing took place. The soil was then flooded for another period of 6

weeks. Thus it was leached 95 days altogether. The flooding was begun on November 16, 1929, and was discontinued on May 10, 1930.

Guar seed was sown June 7, 1930, and the plants grew well on the areas that had supported a good growth of sesbania the previous season. On the other hand, very little growth was made where sesbania had failed the previous summer. It is interesting to note that a growth of sesbania (fig. 3) sprang up over the entire area during this second season. Possibly much of the sesbania seed sown the previous year did not germinate until the second season after planting.

Fig. 3.—This photograph (August 20, 1930), taken from the same place as that of figures 1 and 2, shows the growth of sesbania immediately after the soil had been leached.

The covercrop was plowed under during the latter part of August, 1930, and a good seed bed was prepared by disking and cultivating. Alfalfa, sown October 15, 1930, germinated well over the entire area. The young alfalfa plants seemed to be stimulated by the manure that had been applied to certain plots at the beginning of the experiment (see table 1), but this effect was not observed after the first cutting. A good yield of alfalfa hay was obtained from every one of the plots. Since the first cutting there has been no perceptible difference in the growth of the alfalfa on the different plots.

Soil Analyses.—Soil samples were drawn from each of the plots in February, 1929, before the experiment was begun. At 30 different places on each plot the samples were taken in foot sections down to a depth of 4 feet. The plots were again sampled in December, 1931, more than a year and a half after the soil had been leached. A composite sample of each foot layer was prepared and a 1 to 5 water extract of each sample was analyzed. The results are given in tables 2 and 3.

TABLE 2

Water-Soluble Salts in Soil from Treated Plots*
(Milliequivalents per 100 grams)

Depth, in inches	Carbonate (CO_3)	Bicarbonate (HCO_3)	Chloride (Cl)	Sulfate (SO_4)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)†
Before treatment and leaching (1929)							
0–12..........	0.00	0.29	57.21	7.24	19.35	11.30	34.09
12–24..........	0.00	0.30	20.06	3.81	4.94	3.07	16.16
24–36..........	0.00	0.33	12.05	2.89	2.45	1.71	11.11
36–48..........	0.00	0.40	10.77	3.36	1.91	1.69	10.93
After treatment and leaching (1931)							
0–12..........	0.00	0.51	0.32	1.82	0.94	0.60	1.11
12–24..........	0.00	0.50	0.74	3.06	0.86	0.55	2.89
24–36..........	0.06	0.58	1.07	3.62	0.47	0.40	4.46
36–48..........	0.06	0.59	1.94	5.81	0.75	0.57	7.08

* Average of the 6 treated plots.
† Calculated.

TABLE 3

Water-Soluble Salts in Soil from Untreated Plots*
(Milliequivalents per 100 grams)

Depth, in inches	Carbonate (CO_3)	Bicarbonate (HCO_3)	Chloride (Cl)	Sulfate (SO_4)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)†
Before leaching (1929)							
0–12..........	0.00	0.25	63.67	7.77	21.51	12.34	37.84
12–24..........	0.00	0.30	18.25	3.64	5.00	2.92	14.27
24–36..........	0.00	0.35	11.80	2.87	2.47	1.88	10.67
36–48..........	0.00	0.44	9.39	3.69	1.99	1.64	9.89
After leaching (1931)							
0–12..........	0.00	0.56	0.36	1.24	0.60	0.44	1.12
12–24..........	0.00	0.49	0.63	2.63	0.61	0.49	2.65
24–36..........	0.06	0.52	0.97	3.34	0.46	0.57	3.86
36–48..........	0.08	0.62	1.65	4.95	0.54	0.57	6.19

* Average of the 3 untreated plots.
† Calculated.

The soil originally contained a large amount of soluble salts. Chloride was most concentrated in the upper 4 inches of the soil. In certain portions of the area, crystals of sodium chloride, sodium sulfate, and calcium sulfate were found at a depth of 2 or 3 inches. Calcium chloride was also concentrated on or near the surface. The original samples also contained large amounts of sulfate and magnesium.

Fig. 4.—Alfalfa, photographed June 7, 1932. The photograph was taken from the same place as that of figures 1, 2, and 3. (From Hilgardia, Vol. 8, No. 5.)

A comparison of the analyses of the samples taken in December, 1931, after the soil had been leached, with the samples taken before the experiment was begun (tables 2 and 3) shows that the concentration of the soluble salts was reduced greatly by the leachings. This is especially noticeable in the case of the chloride.

The sulfate was also reduced but not so much as the chloride, especially in the subsoil. The water used for irrigation contained an appreciable amount of sulfate (see p. 4) which, of course, was added to the soil with the water. Therefore, more sulfate was removed from the soil by leaching than is indicated by the analyses.

The content of soluble sodium and magnesium was very markedly reduced in all the samples. Small amounts of normal carbonate were found in the third and fourth-foot samples after leaching.

A comparison of the analyses of the various plots (tables 2 and 3) shows that the soluble salts were removed from the untreated plots fully as well as from the treated plots.

A large percentage of the replaceable base content of the soil is in the divalent form, namely that of calcium and magnesium.[7] It is possible to leach soluble salts from soil of this nature without destroying its permeability. This was proved by the growth of the sesbania and alfalfa and by the fact that the experimental plots have readily absorbed the water applied as irrigation ever since these crops were planted.

Yield of Alfalfa Hay.—Alfalfa sown in October, 1930, gave a complete stand over all the plots. Large yields of hay (fig. 4) were secured during the seasons 1931, 1932, and 1933 (table 4).

TABLE 4

YIELD OF ALFALFA HAY FROM EXPERIMENTAL PLOTS
(Pounds per acre)

Plot No.	1931	1932	1933	3-year total
10*	10,342	10,240	8,620	29,202
11*	10,434	11,110	8,400	29,944
12†	13,098	13,380	9,920	36,398
13	10,906	12,960	9,820	33,686
14	10,040	12,430	10,120	32,590
15	11,742	13,774	10,780	36,296
16	13,146	15,570	10,500	39,216
17	13,178	14,030	9,740	36,948
18‡	11,678	12,100	8,280	32,058
Average	11,618	12,844	9,575	34,037

* The plants on certain parts of plots 10 and 11 were scalded each year.

† Plot 12 originally contained less alkali than the other plots.

‡ Plot 18, which was adjacent to an old alfalfa planting, was badly damaged by the alfalfa caterpillar. This was also true of a portion of plot 17.

The optimum production of hay was undoubtedly reduced by the ravages of the alfalfa caterpillar during July, August, and September of each year, but in spite of this fact good yields were obtained. In 1931, the first year after seeding, an average yield of 11,618 pounds of hay per acre was obtained. The average yield in 1932 was 12,844 pounds, and 9,575 pounds per acre in 1933. The 1933 yield was adversely affected not only by the attack of caterpillars, but also by an insufficiency of irrigation water. The plots were not irrigated between July 23 and September 25, 1933. Consequently the number of cuttings for this year was at least two less than normal for the Valley. The loss of these two cuttings reduced the yield of alfalfa hay by at least 4,000 pounds per acre.

Composition and Level of Ground Water.—The ground water in the sandy strata underlying the experimental plots contains large amounts of soluble salts (table 5). As already stated, the installation of a drain ditch at the beginning of the experiment lowered the water table and

[7] Kelley, W. P., and S. M. Brown. Base exchange in relation to alkali soils. Soil Sci. 20:477–495. 1925.

removed a portion of the soluble salts that had accumulated in the soil. However, in order to leach all the salts down below the root zone it was necessary to flood the land and to keep the water table well below the surface of the soil.

Ground water which contains soluble salts, such as are shown in table 5, is a constant menace to the surface soil, and great care should be taken to provide good drainage conditions continuously. Otherwise the benefits of leaching will be temporary and alkali conditions of extreme severity will again develop in the soil.

TABLE 5

Composition of Ground Water from Six Wells in the Experimental Plots, February 8, 1933

(Milliequivalents per liter)

Sample No.	Bicarbonate (HCO_3)	Chloride (Cl)	Sulfate (SO_4)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
1	2.00	329.63	43.91	81.50	66.16	227.88
2	2.00	267.76	52.06	66.00	58.66	197.16
3	2.00	250.72	61.31	63.00	53.25	197.78
4	2.39	266.70	62.77	67.50	58.66	205.70
5	2.39	390.56	48.46	105.00	81.58	254.83
6	2.00	303.66	52.83	80.00	61.92	216.57

By the use of four test wells outside the experimental area it was found that the depth of the water table remained fairly constant during the first season of the experiment. In one well, located near a frequently irrigated alfalfa planting adjacent to the experiment, the depth to ground water varied from 6 feet to 6 feet 9 inches, while in another well, located at some distance from any irrigated area, the depth to ground water varied from 8 feet 1 inch to 8 feet 10 inches. The depth to ground water in the other two wells, which were within 50 feet of the experimental area, was about 7 feet 4 inches.

While the plots were being flooded, the water rose to within 7 feet of the surface in three of the test wells and for a brief period to within 4½ feet of the surface in one of them. However, with the discontinuation of the flooding, the ground-water level receded and has remained at from 6 to 9 feet from the surface since that time.

The soil and alkali conditions on the experimental plots are typical of those of large areas in the Imperial Valley. In certain sections ground water of similar composition stands at the present time within 2½ to 3½ feet of the surface of the soil. In such places the soil is devoid of even the most alkali-resistant plants, and the surface is covered with a crust of salt. It is absolutely necessary to lower the water table under these areas before reclamation can be successful.

DISCUSSION

The alkali-reclamation problem in the Imperial Valley is primarily a question of removing white-alkali salts from the soil to the depth usually occupied by plant roots. These soluble salts may be present on the surface or at varying depths in the subsoil. In many instances the soluble salts now present on or near the surface of the soil were brought up from the subsoil by a rising water table.

Reclamation experiments located on soil typical of a large portion of the alkali area of the Valley have shown that it is possible to remove the salts and to reclaim the soil.

The Colorado River water which was used for irrigation and leaching contains as much total soluble calcium and magnesium as sodium compounds, as is shown on page 4.

The content of soluble calcium in the soil and irrigation water is especially important, since it obviates the necessity of adding calcium to the soil.[8] This also accounts for the fact that the plots which were leached, but otherwise untreated, gave as good results as those which were treated with gypsum, sulfur, manure, or combinations of these materials. Tables 2 and 3 show that leaching with water alone removed the soluble salts from the soil of the untreated plots as well as from the soil of the treated plots; apparently the water moved through the untreated soil as well as through the treated soil. Under such conditions, the limiting factor in the reclamation will be the type of soil rather than the amount of soluble salts present. For example, a heavy clay soil with finely divided particles will permit water to move through it less freely than a soil which is composed of larger particles. The soil of the plots under consideration and the water which was used for irrigation contained a sufficient amount of calcium and magnesium compounds to flocculate the soil; consequently water moved through both the untreated and the treated soil, leaching out the salts equally well in both cases and restoring good conditions for crops uniformly throughout all the plots.

In this work, as in the work near Fresno, California,[9] drainage was found to be the first essential to alkali-soil reclamation. It seems justifiable to assert that without reasonably good drainage, successful alkali reclamation is impossible.

Fortunately, the water table can be lowered in soils of the Holtville and Rositas series. These soils are underlain with pervious, coarse-tex-

[8] Kelley, W. P., and S. M. Brown. Principles governing the reclamation of alkali soils. Hilgardia 8(5):149–177. 1934.

[9] Kelley, W. P., and E. E. Thomas. Reclamation of the Fresno type of black-alkali soil. California Agr. Exp. Sta. Bul. 455:1–37. 1928.

tured subsoils through which water moves more or less readily; hence, the surplus water can be removed by installing drain ditches or drain tile. However, the Imperial and Meloland series of soils present a somewhat different problem. These soils are underlain with fine-textured, slowly pervious subsoils through which water moves very slowly. In many cases the ground water can be removed by the installation of lateral drain ditches or by closely spaced tile drains. However, in localities where the subsoil is heavy, such a method might be commercially impractical because of the great number of ditches or drains needed to accomplish satisfactory leaching.

Generally speaking, the soluble salts in each of these four series of soils are similar to those of the experimental plots discussed in this bulletin and can be removed by leaching wherever drainage is possible.

After the salts have been removed from the surface by leaching and drainage, the next step is to prepare a good seed bed and plant some crop such as alfalfa. During the first few years of the reclamation, crops that require flooding types of irrigation should be grown. Alfalfa is well suited to this purpose. Under these conditions the soluble salts will be driven downward somewhat with each irrigation, so that in the course of time they will be satisfactorily leached down below the zone of normal root development.

Much greater care must be given to the farming operations on alkali soil, or that which is being reclaimed, than on normal soil. In the first place a good seed bed is most essential in order that satisfactory germination may be secured. More seed should be sown than is ordinarily used. The soil should contain sufficient moisture at planting time to germinate the seed; thus the first irrigation may be delayed. This is highly important on a heavy clay or clay loam soil, for after irrigation there will be formed a hard surface layer which may seriously interfere with the germination and growth of the young plants.

During the growth of the crop, the amount and time of application of irrigation water should be such as will facilitate the movement of water through the soil. The water should be kept moving downward rather than upward toward the soil surface. The irrigation should be frequent during the young seedling stage of growth. The water thus applied will dilute the soil solution and lower the concentration of soluble salts. It is advisable to irrigate young alfalfa at 2-week intervals and in some instances once a week.

SUMMARY

The soils of the southern part of Imperial Valley were formed by the deposition of material brought down by the Colorado River. The deep subsoils contain relatively large amounts of soluble salts consisting mainly of the chlorides and sulfates of sodium, calcium, and magnesium. Poor drainage conditions have resulted in a high water table and the consequent accumulation of alkali near the surface of the soil.

The concentration of soluble salts brought to the surface by the capillary rise of water from the high water table has become excessive in many places.

Reclamation experiments have demonstrated that white alkali, such as that found in the Imperial Valley, can be leached out provided the drainage conditions are favorable. No special treatment with materials such as gypsum and sulfur is needed. The untreated leached plots of the experiments gave as good results as those that were treated and leached.

The water table must be kept well below the root zone if good results are to be expected. For this reason good drainage conditions are essential.

After the salts have been leached out, a good seed bed should be prepared before seeding to any crop, and at planting time the soil moisture should be sufficient to insure germination without the necessity of irrigation.

The young alfalfa should be irrigated frequently to prevent excessive drying out and to promote the downward movement of water; the soluble salts will thus gradually be leached deeper and deeper into the subsoil and ultimately out into the drainage system.

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